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ASSOCIATION
European Atomic Energy Community - EURATOM
Centre d'Étude de l'Énergie Nucléaire - CEN

THE BR 2 TESTING REACTOR AND ITS CONNECTED LABORATORIES

Annual Progress Report 1965

1966

Work performed at the
Centre d'Etude de l'Energie Nucléaire — CEN/SCK, MOL, Belgium
BR 2 Operating Group

Association No. 006-60-5 BRAB

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CONTENTS

KEY TO THE FIGURES

KEY TO THE TABLES AND DIAGRAMS

The BR 2 Testing Reactor and its Connected Laboratories (*)

1. SUMMARY

Operation of the BR 2 and its associated installations was carried out on the basis of the Contract of Association signed between EURATOM and the CEN. By the terms of this Contract, concluded in 1960 for a period of 20 years, the parties concerned use the installations, which are operated jointly, for their own purposes: they may also make them available to any other parties they please for the latter's requirements. Implementation of the Contract is directed by a Management Committee, which met five times in 1965 to draw up the programmes and tend to the technical coordination of the various uses being made of the installations.

The advantage obtained by the major European nuclear projects from the high neutron fluxes in the BR 2 reactor—both slow and fast neutrons—was further confirmed. The number of materials tests increased and some 150 devices were irradiated during the year, not including the small isotope cans, so that 35-40 channels were continuously occupied in the reactor.

Among the main experiments carried out, mention should be made of the graphite, beryllium, zirconium, steel and plutonium irradiations for the CEA (French Atomic Energy Commission) (gas/graphite, heavy-water/gas and fast-reactor systems), the graphite, steel and beryllium irradiations for the UKAEA (chiefly the AGR system), the graphite irradiations for the OECD DRAGON project and for the KFA-Jülich THTR project, structural-material irradiations for the Karlsruhe Research Centre (fast reactor programme), various irradiations for the German companies Interatom and Nukem, the preparation of loops for the German companies of Siemens Schuckert and Babcock & Wilcox, several irradiations for the Belgian organisations Belgonucléaire, CNRM, SERAI, and UMHK, and numerous irradiations for the parties to the Contract of Association themselves, CEN and Euratom, including in particular the irradiation of an ESSOR fuel element for the ORGEL project. Production of radioisotopes (high-specific-activity cobalt, iridium, transplutonium elements) was also undertaken on behalf of Euratom, CEN and industrial firms. In addition the CEN physicists continued their work on neutron beams.

The report reviews the main devices in the context of the overall programme, which frequently covers a period of more than one calendar year.

Generally speaking, irradiation devices have increased in complexity; in particular, several experimenters have made their regulated capsules mobile in order to keep the targets in the desired conditions. During 1965, successful irradiations were carried out on

(*) Manuscript received on July 20, 1966.

the first capsules and the first molten-metal loops (MFBS) constructed by the BR 2 Operating Group (GEX).

The geometry of the reactor core was modified in the course of the year. It was enlarged in order to obtain more irradiation channels and the maximum thermal flux was raised to 10^{15} n/cm^2/sec. This change necessitated a period of tests which, combined with a period devoted to maintenance of the installations, lasted more than a month. This accounts for the reduction in the number of operating days compared with the previous year (190 in 1965 against 222 in 1964). No noteworthy incidents occurred. Unscheduled control-rod drops, so frequent in 1964, were virtually non-existent in 1965. On the other hand, several unforeseen shutdowns were caused by (six) tube breakages in the main heat-exchangers.

Several new units were added to the installations in order to increase operating safety and come more into line with the experimenters' requirements. In particular, all the medium-activity hot laboratories were to be commissioned and officially opened on 14 December.

2. FABRICATION AND DEVELOPMENT OF IRRADIATION DEVICES

Of the 150 devices irradiated in 1965—a figure which does not take account of the small isotope cans—more than two-thirds were fabricated by GEX, the rest being made by the experimenters themselves.

Fabrication of the experimental devices necessitated the development of special techniques in the field of instrumentation and the use of molten metal. In this latter field, the results were highly satisfactory; during 1965, successful irradiations were carried out on the first capsules and the first molten-metal loop constructed by GEX.

All the devices were subjected to very close supervision in order to enable the irradiations to be performed with the least possible delay and in accordance with the experimenters' requirements. There was further fruitful cooperation with the leading nuclear enterprises in the Community and the United Kingdom.

A condensed survey of the irradiation devices used in BR 2 formed the subject of a paper delivered at the EAES symposium held in The Hague in September.

The main devices are now reviewed in the context of the overall programmes, which in many cases cover periods of more than one calendar year.

2.1. Loops

The DRAGON Loop

The very-high-temperature gas-loop designed for the Dragon project (OECD) and the first GEX project in this field has become the property of GEX. By means of this loop, graphite samples in a helium flow at a pressure of 10 kg/cm^2 can be exposed to an intense radiation field. Irradiation can be carried out over a wide range of temperatures, if necessary up to 1500 °C. The principal aim of the tests is to determine the influence of the radiation on the mass-transfer phenomena in respect of graphite in an atmosphere of helium with well-defined impurity contents.

The in-pile tests were launched at the beginning of 1963; they were continued in 1964 and 1965 in a total epithermal flux of 10^{15} n/cm^2/sec. In 1965, three single-cycle irradiation programmes were carried out—two for THTR and one for DRAGON.

The tests were directed to the fundamental study of radiation effects by means of a new technique. The graphite samples are labelled with ^{14}C and the corrosion products, in the form of CO_2 or CO, are measured at the outlet of the device. By this method, the graphite corrosion can be determined in a few hours; thus 70-80 experimental points can be obtained during an irradiation programme. By the weight-loss measurement method, only one experimental point per cycle was obtained.

Investigations are currently being conducted into the possibility of utilizing CO_2 in the loop instead of helium so as to meet new experimenters' requirements.

MFBS Loop

The MFBS loop, with sodium as a coolant, was constructed by GEX on behalf of the CEA and is designed to irradiate, at a high neutron flux, fissile pins to be used in a fast-neutron reactor. The object is to obtain a high power density level and minimum radial distortion.

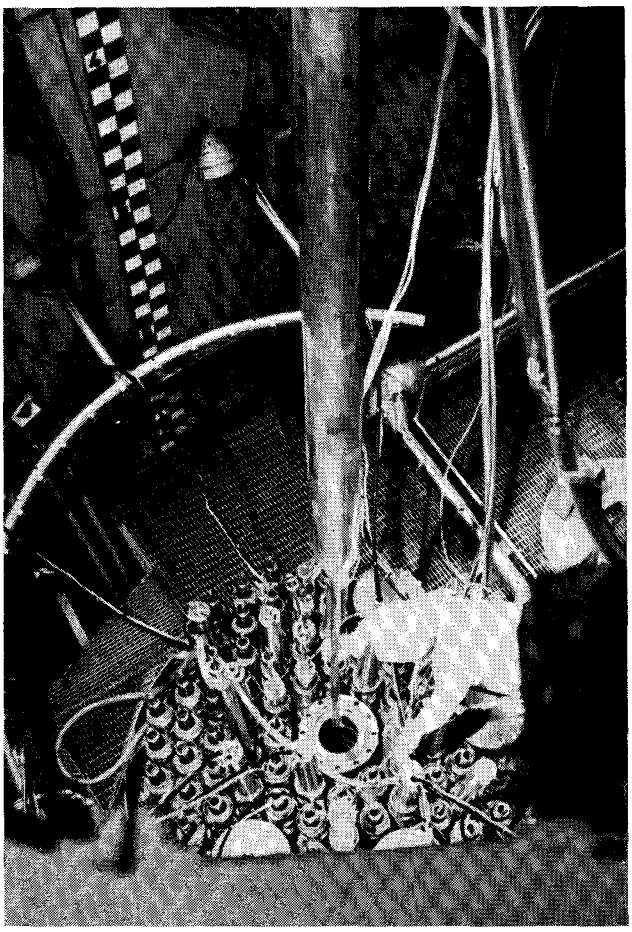


Figure 1

Insertion of the MFBS sodium loop into the central channel of the reactor. The plutonium needle is in the lower part of the thimble.

The primary circuit includes a group of two electro-magnetic pumps mounted in series which are capable of circulating 1 l/sec sodium at a pressure of 1.5 kg/cm^2. The sodium-gas exchanger is capable of dissipating a thermal power of 130 kW. The remaining equipment consists of preheating electric circuits, measuring thermocouples and various shielding. The assembly is highly instrumented, 21 thermocouples being fitted at various points in the circuit. In the lower thimble introduced into the core, the sodium forms a back-and-forth movement in two concentric tubes; the fissile pins are positioned in the internal tube, the external tube consisting of a sheathing containing boron carbide; the whole unit is surrounded by the pressure tube. In order to obviate the action of the thermal neutrons, the fissile assembly has extensions above and below in the form of two boron-carbide plugs and the pressure tube is surrounded by a composite layer, the innermost part of which is a cadmium core cooled by the reactor's primary water circuit.

After an intensive out-of-pile test programme, the MFBS loop was inserted in the reactor for a period of ten days. During this period, three unscheduled reactor shutdowns occurred, none of which was due to the loop. The temperature of the sodium in the section downstream of the fuel pins initially fixed at 400 °C, was raised to 410 °C after a few hours' irradiation. The heat dissipation in the fissile pins (mixed uranium-plutonium carbides) was approximately 2100 W/cm^3, the temperature in the centre of the pins being about 1500 °C. Dismantling was carried out in the shielded cell without any incident.

It is planned to construct two new in-pile sections in 1966 in order to carry out two irradiation programmes totalling 80 days. Use of the loop is also envisaged for other fast-reactor programmes (GFK and CNEN). For this purpose, studies have been carried out with the aim of adapting the in-pile part in order to increase the number of fissile pins, step up the temperatures and raise the effective neutron fluxes by adding the fuel at the thimble periphery.

Siemens Loop

The high temperature and pressure (CO_2 at 600 °C and 60 kg/cm^2) gas loop is intended mainly for testing prototype fuel assemblies in order to determine their final performance.

The overall design and construction were carried out by the SERAI company for the firm Siemens-Schuckert (Erlangen). The fine regulation of the loop will be carried out by the GEX personnel. During the last quarter of 1965, the competent staff have familiarized themselves with the installation; the in-pile tests will start early in 1966 and will last for several years. Various UO_2-base fuel elements will be irradiated.

Babcock Loop

The project relating to the high-pressure gas loop for structural materials (CO_2 at 60 kg/cm^2) was pursued by the firm Babcock-Wilcox (Oberhausen). The loop is designed to permit the irradiation of graphite samples swept by CO_2 with well-defined impurity contents.

The installation consists mainly of a primary circuit, to which is connected in parallel a clean-up circuit for controlling the gas and correcting its impurity content. The in-pile section is blind and is positioned in a three-tube fuel element.

For the purposes of this project, the rôle of GEX is to assist the experimenter by supplying him with as much information as possible for the detailed study and for the problems relating to dosimetry, examination of the samples and evacuation of the radioactive waste.

The irradiations are due to start at the end of 1966; several in-pile sections will be constructed by the experimenter. This work forms the subject of a contract concluded between EURATOM and Babcock.

2.2. Regulated capsules

Numerous experimental devices in which it is possible to regulate the target temperature have been constructed.

Boiling-Water Capsule

The irradiation device called the "boiling-water capsule" enables the power released by a fissile pin to be measured continuously.

The targets are set in the centre of a nickel cross brazed inside a stainless steel tube. NaK provides the heat-conducting bonding between the cross and the target. The cavities delimited by the lateral surfaces of the bars of the cross and the stainless steel sheathing tube are filled with helium. The assembly is immersed in pressurized water in a second stainless steel container. The heat flow is controlled by thermocouples placed in the arms of the cross and in the pressurized-water container.

The device and the control rig were designed and constructed by GEX for the EURATOM-CEN-Belgonucléaire plutonium project. A first capsule was inserted in the reactor during the 9/65 cycle; its behaviour at 250 W/cm proved satisfactory. At the end of 1965, two other capsules and a second panel were in course of assembly.

Studies and tests are in progress with a view to increasing the dissipated power per unit length and achieving ratings of 400-600 W/cm in the case of the plutonium-oxide pins.

"Unswept" capsule for spherical fuel elements

A capsule for irradiating fuel pellets has been developed for the THTR project. The active part is designed to take two pebbles 60 mm in diameter representing fuel elements used in the AVR or THTR project.

The spheres are of graphite and contain fissile material in the form of coated particles, the rated fission power released by each pebble being 2 kW. The surface temperature of the spheres is 1000 °C and that of the graphite cylinder and their stainless steel cladding is approximately 500 °C. Regulation is carried out by means of gas shielding.

The design and technical development of the device were carried out in 1965 by GEX; a first capsule is in the course of assembly and will be inserted during the first quarter of 1966.

"Unswept" capsule for coated fissile particles

An apparatus has been designed for enabling coated fissile particles to be irradiated at very high temperatures; it is similar to that used for fuel pellets, only the target part being different. The particles are stacked in a graphite cylinder, which in turn is placed in a leaktight stainless-steel box. The desired temperatures range from 1200 to 1500 °C.

The design and technical development were carried out by GEX on behalf of the THTR project; at the end of 1965, a first capsule was in the course of construction; during the second half of 1966 it will be inserted in the reactor.

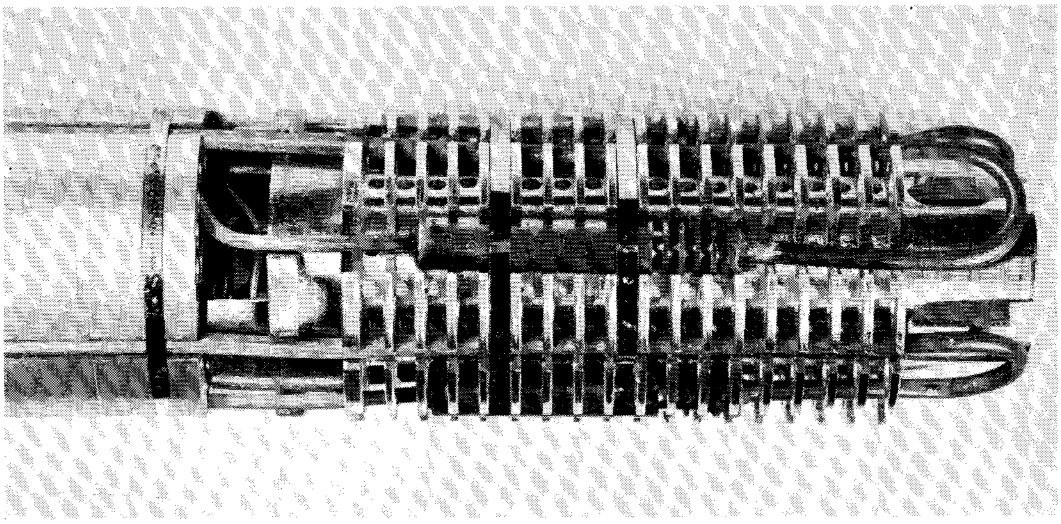


Figure 2
Supply to the high-power heating coils for a regulated capsule.

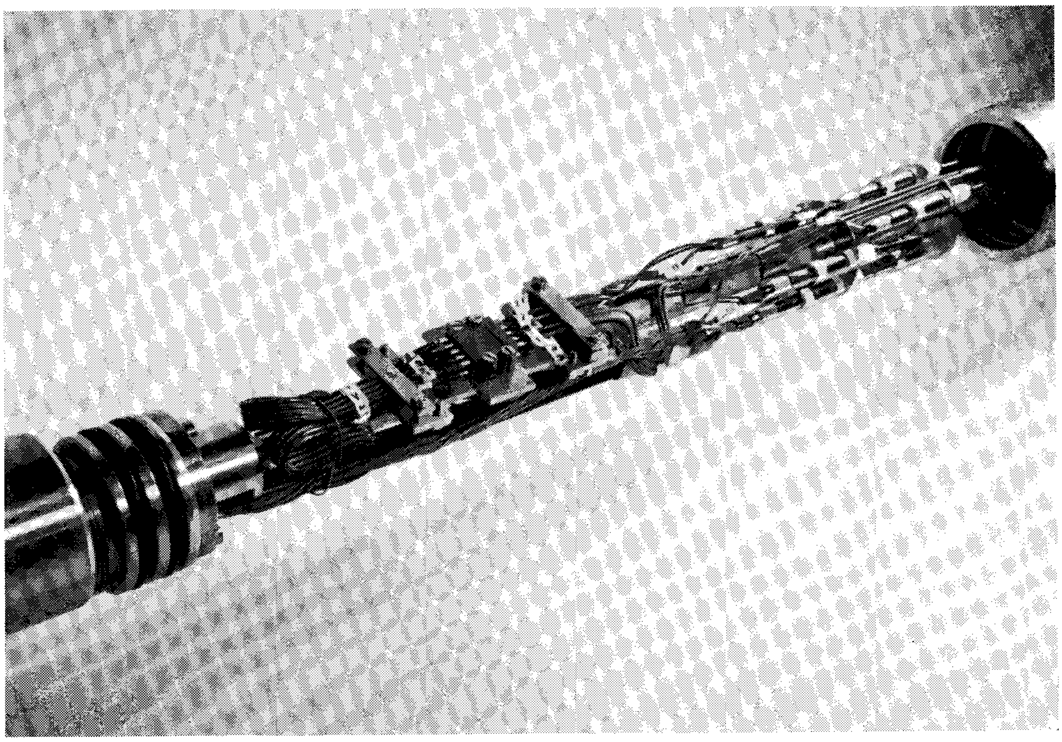


Figure 3
Hot-wire and thermocouple junctions for a regulated capsule.

"Swept" capsules for spherical fuel elements and coated particles

The THTR project has shown considerable interest in "swept" devices for spherical fuel elements and for coated particles. The preliminary studies have been undertaken by GEX in collaboration with Vickers Armstrong (Engineers) Ltd.

Medium temperature heated graphite capsule

A device has been constructed for the irradiation of medium temperature (150-350 °C) graphite samples on behalf of the French CEA.

The graphite samples are placed in a cylindrical sheath around the outer surface of which a thermocoax-type heating wire is coiled. The heating sheath is in turn placed in a clad and the whole is inserted in an aluminium box-tube with a carefully calibrated internal diameter. Between the clad and the box-tube is a very narrow annular space forming a static thermal barrier; there is no gas sweeping.

The devices are assembled in their entirety by GEX from calibrated equipment constructed by the CEA (targets and heating sheaths). By the end of 1965, there were three devices in the pile. The programme will be continued in 1966. It is expected that two to three devices will be placed in-pile simultaneously.

Miscellaneous

Close cooperation has been maintained with those experimenters who constructed their own devices and also with outside manufacturers. There has been a particularly large-scale pooling of information with the French CEA, the Karlsruhe Research Centre (GFK), the Petten Research Centre (JRC - EURATOM) and the United Kingdom Atomic Energy Authority (UKAEA).

In particular, the French CEA has embarked upon the construction of two types of furnace for irradiations in BR 2 of RAPSODIE and heavy-water/gas structural materials. These are the Chouca-D and Cobra furnaces, series production of which will be started in 1966.

— A first Chouca-D furnace was inserted in the reactor at the 11/65 cycle and enabled steel samples immersed in sodium to be irradiated at 550 °C. A second irradiation programme with samples heated up to 650 °C will start in January 1966.

— A "beryllium corrosion" device was inserted at the last 1965 cycle in a Cobra furnace.

The Karlsruhe Research Centre (GFK) has studied and constructed a device for studying in-pile creep in structural materials.

The cladding material tubes form the actual containment of a capsule which is electrically heated internally and pressurized by helium.

A dual irradiation programme is planned (two devices in parallel in channels with similar characteristics), as also is the construction of some twenty test sections. By the end of 1965, the out-of-pile tests at the Karlsruhe Centre were under way, while the irradiations will start during the second quarter of 1966. GEX is responsible for the entire installation of the equipment.

The Petten Research Centre (JRC-EURATOM) has studied and constructed a device for irradiating steel and zirconium hydride samples for the Interatom company (Bensberg).

The samples, which are in the form of tensile-test specimens, are placed in stainless steel leaktight containers immersed in sodium. Each container has a SAP cladding. Between the cladding and the aluminium tube-sheathing is an annular space—gas shielding forming a thermal barrier. The entire capsule can be shifted axially with a 200 mm travel. The device is designed for insertion in a five-plate fuel element with no support tube.

Two capsules were constructed at the same time and inserted at the end of 1965, one for a single-cycle irradiation, the other for a three-cycle irradiation.

The United Kingdom Atomic Energy Authority has carried out, in the BR 2 reactor, irradiation programmes on structural materials for its Harwell and Culcheth centres. The majority of these irradiations were under the AGR (Advanced Gas Reactor) programme. Particular mention should be made of the devices for irradiating graphite in temperature ranges up to 1200 °C, beryllium oxyde in temperature ranges up to 950 °C, and stainless steel (650°), as well as for carrying out irradiations for determining the influence of radiation on creep and the dimensional characteristics of materials.

The irradiations are carried out in high neutron fluxes, all the devices being placed in fuel elements. In 1965, irradiations of UKAEA capsules accounted for 51 % of the fuel element irradiations.

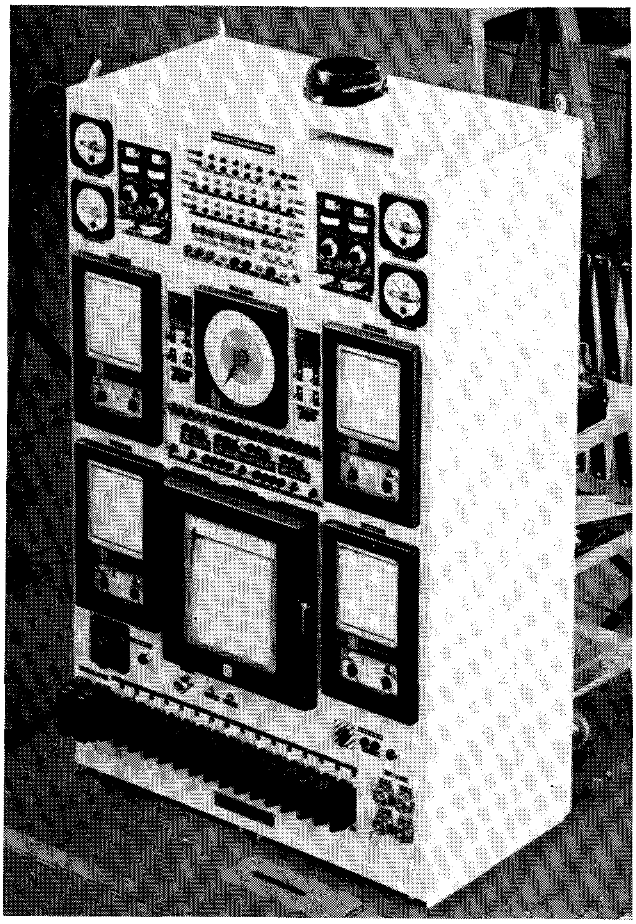


Figure 4

Control console designed for the temperature control of four furnaces.

A very-high-temperature type of graphite capsule has been constructed by an outside firm for the THTR project. The active part of the device contains a tungsten sample-holder which can take graphite samples.

The sample temperatures range, depending upon the capsule, from 900 tot 1200 °C; they are obtained mainly by nuclear heating with a tungsten generator.

Three capsules were irradiated during 1965.

An outside firm has started construction of mixed-type regulated devices for graphite irradiations, which are being carried out on behalf of Siemens-Plania and the Karlsruhe Technische Hochschule.

During the irradiations, the temperatures of the samples will be raised to about 700 °C; at regular intervals, the samples will be extracted, examined in the hot cell and reinserted in a new device. There will be four irradiation programmes, the first of which will start early in 1966.

An outside firm has started work on the study and construction of gas-shielding regulated devices for long-time irradiations of structural materials on behalf of the Karlsruhe Research Centre (GFK); the samples will be heated to 600 °C. Two neutron-flux channels will be necessary for two irradiations in parallel, each of which will take about 12 months as from mid-1966.

2.3. Instrumented capsules

Several irradiation devices fitted with thermocouples only have been constructed for both fissile-material samples and structural materials.

Steel-Irradiation Capsule

A device for irradiating steel samples has been designed for a metallurgic research programme undertaken by the CNRM (Liège).

The samples, mainly Charpy specimens, immersed in a sodium-potassium eutectic solution, are placed in a stainless steel leaktight case, their temperature being between 300 and 400 °C.

The first capsule was irradiated during the second half of 1965. The technological information required enabled the design of the subsequent capsules to be improved. By the end of 1965, the studies relating to two new capsules had been completed.

Instrumented Fuel Elements

A number of BR 2-type concentric-layout instrumented fuel elements and an ESSOR element were inserted in the reactor. Irradiation of the ESSOR element was on behalf of EURATOM (ORGEL Project, Ispra). The fuel element was equipped with five thermocouples fixed in an external plate and three thermocouples inserted in a stiffener. A complete set of measurements was carried out on this element in the dry state by the manufacturers before it was inserted in the reactor. After it had been withdrawn, it was again subjected to a complete set of measurements under water.

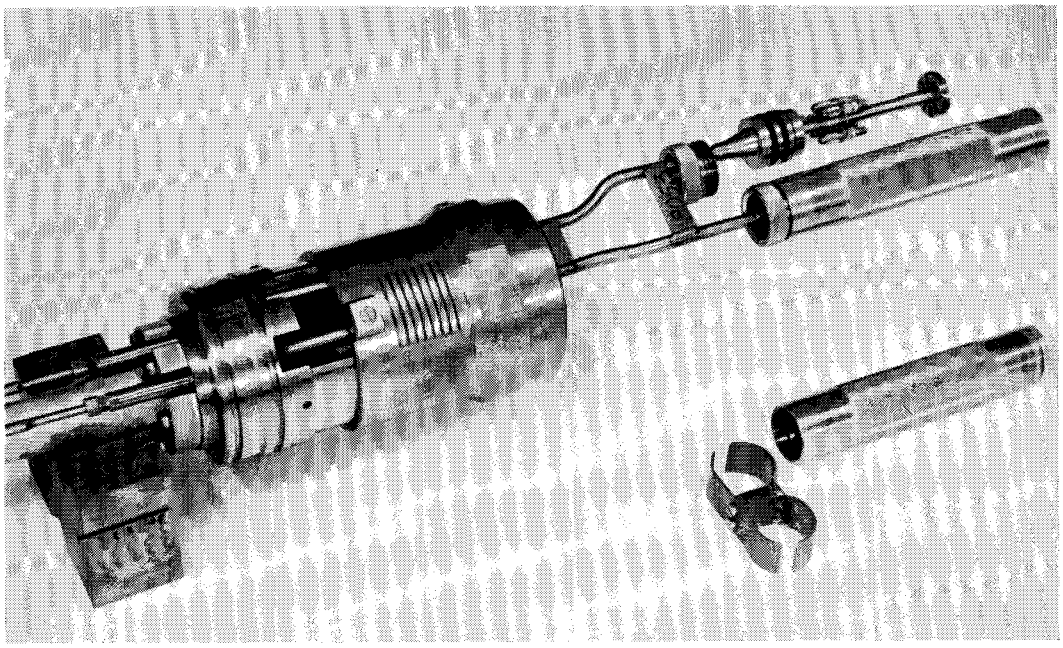


Figure 5
ESSOR fuel-element head showing the outlet of the miniature thermocouples housed in the cladding of the fuel plates which were irradiated in BR 2.

Miscellaneous

Close technical links have been maintained with various experimenters who are building instrumented irradiation devices.

A device containing a sample-shifting mechanism was constructed by the SERAI Company for the Mitsubishi Company, being designed for the irradiation of aluminium-alloy-clad ordinary steel. One of the salient features of this design is that it enables the samples to be shifted azimuthally or axially discontinuously by manual control. In this helium-filled leaktight device are placed four lots of samples. The temperature is raised by gamma heating. The temperature differential between the lots is obtained by encasing the samples in lead and tin alloy sheathings. One such device was inserted in the reactor at the end of 1965; another is to be inserted at the beginning of 1966 and a third in mid-1966.

A study has been carried out by the French Atomic Energy Commission (CEA) on a type of capsule to be used in irradiations of fissile pins immersed in sodium. The experimenter started on the construction of a device in which the fissile pins, when subjected to a high thermal density, undergo core-melting. Several technological problems had to be solved, in particular the use of niobium for the fabrication of the sheathing for the device. As the experimenter wishes to know the fission density with a high degree of accuracy, a full dosimetry programme will be carried out in the BRO 2 reactor. The nuclear model has to all intents and purposes been completed; the device itself will be ready during the first half of 1966.

A capsule containing sintered PuO_2-UO_2 pellets is being developed by the Institute for Transplutonium Elements at Karlsruhe (EURATOM). The aim of the POM-II project is to study the behaviour of fuel pellets under high burn-up. The detailed study will be carried out in collaboration with GEX.

2.4. Non-instrumented capsules

Numerous non-instrumented devices have been designed, constructed and put in service.

Fuels Rods in Molten Metal

Assembly of a capsule for the irradiation of fuel rods immersed in molten metal has been completed. The design of the capsule, initially the work of the customer (Mitsubishi), has been reappraised in cooperation with SERAI. A new capsule has been built in accordance with checking procedures developed jointly and based on experience acquired. In view of the special nature of the device—non-instrumented, containing NaK and fissile material (slighty enriched UO_2) and with an ordinary sheathing—a complete pilot assembly programme, with intermediate checks, has been drawn up.

The capsule was inserted at cycle 05/65, and is scheduled to be withdrawn at the beginning of 1966.

Fuel-Rod Basket

Work has been completed on the assembly, for SERAI, of a basket for the irradiation of three fuel rods directly immersed in primary-circuit water. The basket was inserted at cycle 12/65 and will be withdrawn in early 1966.

Cladding Materials

The assemblies required for the structural-material irradiation programme to be carried out on behalf of the GFK (Karlsruhe) have been completed. The experimenter wishes to irradiate steel alloy, Inconel and vanadium tensile-test and impact-strength samples. A flow of primary-circuit water plays upon the samples, which are inserted in a six-plate fuel element. By means of flux detectors, the radiation dose received can be determined at the end of the programme.

Four devices were assembled and inserted in 1964 and two more in 1965. A seventh device is to be inserted during the second quarter of 1966.

Cold-State Irradiation of Zircaloy

At the request of the French Atomi Energy Commission, a device for irradiating Zircaloy samples in the cold state has been designed and constructed. The samples are immersed in primary-circuit water and the surface temperature must be below 100 °C.

In the designing of this device, account was taken of the experience acquired during previous irradiations of zirconium samples. Thus the thermocouples were eliminated but the flux-detectors retained. The samples are assembled in a hexagonal-section tube inserted in a fuel element.

The work was quickly completed and the device inserted four months after the request had been made by the experimenter.

Irradiation of Boron-Carbide Particles

A capsule for irradiating boron-carbide particles was constructed and inserted on behalf of Nukem.

The particles are introduced into a graphite matrix; flux-detectors and temperature-indicators are used for subsequent determination of the doses received and for checking that the temperature range (600-1000 °C) has been observed.

Uniform-Dose Device

A uniform-neutron-dose irradiation device has been designed by GEX for use by various experimenters.

In a standard double-access channel, a support rod to which a sample-holder tube is attached can be moved over a length of about four metres, both longitudinally and rotationally. In this way, the sample-holder tube can be rotated and moved about as desired in the radiation field. The entire drive and control mechanism is housed in the lower part of the channel.

The first client intending to use the irradiation device is the Battelle Institute at Geneva. Hence the device has been designed in accordance with special specifications laid down by them.

The detailed study was completed by the end of 1965. The irradiations proper may start during the second half of 1966.

2.5. Capsules for isotope production

Numerous devices for the production of radioisotopes in the interior of the reactor vessel have been designed, constructed and put into service.

Americium Oxide

At the beginning of 1964, a basket containing U.S.-made americium oxide rods was inserted in the reactor. The device was intended for the production of transuranium elements under a Euratom programme. The basket was first placed in an external reflector channel; in 1965, the rods were transferred to another device for insertion in a very high flux in the inner reflector. The rods will be extracted during the first quarter of 1966.

A study has been carried out on a new device for use in the programme relating to irradiation americium oxide capsules of European fabrication (Institute for Transuranium Elements, Karlsruhe); the technical specifications for the new targets were drawn up in conjunction with the experimenter, who is also to build them.

Transplutonium Elements

Studies on a special assembly for the production of transplutonium elements from plutonium-containing plates were continued. The device, which is being designed for the French Atomic Energy Commission, is in the form of a fuel element consisting of slightly curved plates of the MTR type. The use of fillers around the box enables it to be inserted in a reactor standard channel. The fuel cartridge is to be constructed by the experimenter, and the device is to be assembled at GEX. The mock-up for the hydromechanical tests will be available early in 1966; assembly itself may possibly be around the middle of 1966.

Production of Cobalt-60

Production of cobalt-60 by GEX was stepped up during the year.

Work continued on the construction of reflector and fuel-element devices and also on the final adjustments of the control-rod devices. Thirteen devices were inserted in 1965.

Iridium Production

Iridium irradiations were continued on behalf of the CEN, Mol (Radioisotopes Department acting on behalf of the CEA-CEN-SORIN Association), the Iridiumvertriebsgesellschaft (Karlsruhe) and Philips-Duphar (Amsterdam).

The capsules containing the targets are inserted in irradiation baskets which can be re-used. The problems inherent in the routine production of radioisotopes have been carefully coordinated, in particular with regard to the rapid recovery of the hot-cell targets and the various transportation formalities.

Miscellaneous Targets

A whole range of irradiations of various targets, in particular $CaCO_3$, CdO, Rb_2O_3, Ru, SbO_3, Fe_2O_3, In, Ag, Tb_4O_7, Tm_2O_3, MgO and Nd_2O_3, have been coordinated for the Radioisotopes Department of the CEN. Another job carried out for the CEN has been the irradiation of the BR 3/VULCAIN reactor start-up source.

Irradiation Thimble

GEX has undertaken the study and construction of an irradiation thimble. This device, which is in the form of a blind tube, creates an experimental cavity in the reactor, directly linked to the pool. The tube is fixed to the plug of one of the reactor's standard channels; it can hold a mobile apparatus to which a standard reloadable basket is attached. It is thus possible to carry out short-term irradiations over varying periods at a high neutron flux of more than 10^{14} n/cm^2/sec.

The device, which was completed at the end of 1965, will go into service early in 1966.

2.6. Irradiation devices in the pool

In addition to the emergent-neutron-beam tubes, of which there are nine (five blind radials and four duel-access tangentials), the experimental space left free around the reactor vessel skirt at the level of the core can be used for the insertion of irradiation devices of varying design.

Guide Tubes

In 1965, three more single tubes were set up which can be used for irradiations independent of the reactor cycle. In all, four tubes are employed regularly for isotope production.

Fuel-Rod Support

A start was made on the construction of a device for irradiating fissile-material rods in the pool. The first irradiations will be for CEN (Chemistry Department), to be applied to the study of reprocessing problems.

The device, which is mounted on a pivot and capable of translational movement, is designed to take groups of 20 rods of UO_2. A total of 300 rods is to be irradiated.

The studies were completed by the end of 1965, and construction of the assembly (support, basket, tools) commenced. The device is scheduled to go into service during the second quarter of 1966.

2.7. Gamma-irradiation devices

Two gamma-irradiation devices have been operated on behalf of various customers.

Continuous-Sweep Capsule

A capsule with a continuous sweep circuit was constructed in 1964 to round off the tests carried out with the high-temperature gas loop for the DRAGON Project. It can be used to study the influence of gamma radiation on the physico-chemical equilibrium of a mixture of helium and carbon dioxide.

The capsule is inserted into a freshly burned fuel element; the gamma dose varies from $4 \cdot 10^7$ to $5 \cdot 10^6$ rads/hour during a single irradiation programme.

The irradiations started during the last quarter of 1964. The tests were resumed in 1965 and continued up to the middle of that year. At the end of 1965 work was begun on a new measuring technique, the tests on which will be resumed in July 1966.

The tests carried out and coordinated by the DRAGON Project are discussed at regular intervals by a working group (Harwell, Milan, Mol), which, after completing its examination, draws up the new research programme.

Fingal-Glass Capsule

The gamma irradiations of glass (Fingal) to be used for the storage of radioactive residues, on behalf of the UKAEA, Harwell, were continued up to November 1965, having started during the second quarter of 1964, and lasted for about 14 months. The device, which was built by the experimenters, was inserted in a freshly burnt fuel element set in the centre of a ring of other fuel elements. A dose of $1.3 \cdot 10^9$ rads was reached.

2.8. Instrumentation and special techniques

Further studies were carried out in 1965 on special techniques for which there are immediate or short-term applications in various irradiation projects.

Mention should first of all be made of the supplementary research carried out in connection with the improvement of regulated and instrumented irradiation devices, i.e.:

— A method has been developed for the contact-free measurement of the envelope curve of temperatures along an object.

— A very-high-temperature furnace was constructed.

— Work was continued on the development of connections for heating wires with a high power density; efforts were directed to the achievement of very small radii of curvature, the determination of the permissible limit currents, measurement of insulation resistance at varying temperatures and formulation of the plans for a container to check cladding integrity.

— The studies on high-temperature brazing were continued in conjunction with the Metallurgy Department of the CEN.

— The hydraulic-test installations were supplemented by the construction of a stainless-steel water loop.

— Work was continued on the "molten metal" instrumentation (continuous level gauge).

— Techniques were developed for the welding of pipes through which molten metals have passed.

— A study was made of the behaviour of Nicrobraz welds in sodium.

— In addition, a molten metal loop (flow 0.65 l/sec max. temperature 600 °C) was started up; it will be used for corrosion tests and for testing the mechanical behaviour of several items.

All these operations aimed at the future instrumentation of capsules and loops will be continued in 1966 in accordance with the experimenters' requirements.

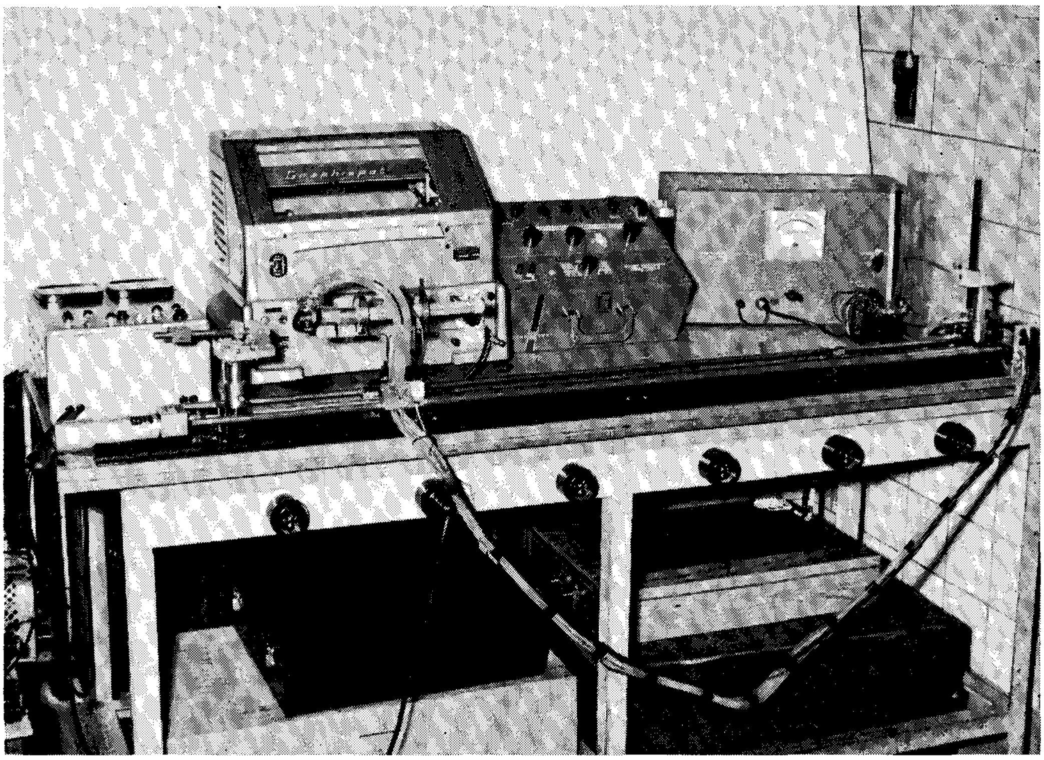


Figure 6

Laboratory for measuring the thermoelectric properties of thermocouple filaments.

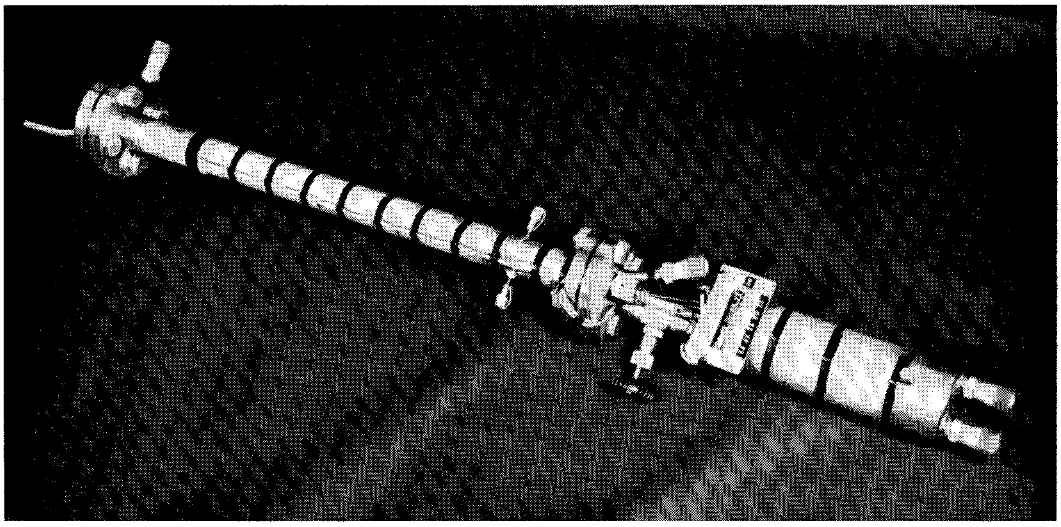


Figure 7

Experimental device for the study of H_2O-NaK reactions

3. VERIFICATION OF THE IRRADIATION DEVICES

The number of incidents which could be set down to technological defects in the experimental devices proved very small in 1965. This was due in part to the efficient operation of the structures set up to ensure trouble-free performance of the experiments by systematically checking them at various stages.

The Experimental Examination Committee responsible for verifying the documents, examines the projects not only from the safety angle but also verifies that the correct working conditions are ensured.

During the year, the Committee met forty times and examined 138 experimental stages. It should be pointed out that these were new experiments, as experiments which are repeated are not usually scrutinized by the Committee.

The material checking of all equipment is carried out by an independent control group. The breakdown of the work of this group for the year is as follows:

Devices checked	*For GEX*	*For Clients*
Loops	4	—
Regulated capsules	5	22
Non-instrumented capsules	28	10
Isotope capsules	50	21
	87	53

This table does not take into account the small standard isotope cans used for irradiations in the pool and in the hydraulic conveyor.

The material checks on the irradiation devices have enabled several structural difficulties to be detected. In particular, the tests carried out on the mobile or reloadable regulated capsules have shown that in many cases the adjustments made in the experimenters' laboratories where inadequate because they had been carried out in operating conditions which do not approximate closely enough to those applying in the reactor. Considerable improvements have had to be made to both the capsules and the test rigs used for them. These improvements were necessary irrespective of the system employed for shifting the samples (manually with hydraulic blocking device, mechanically with manual control, mechanically with electric or hydraulic control).

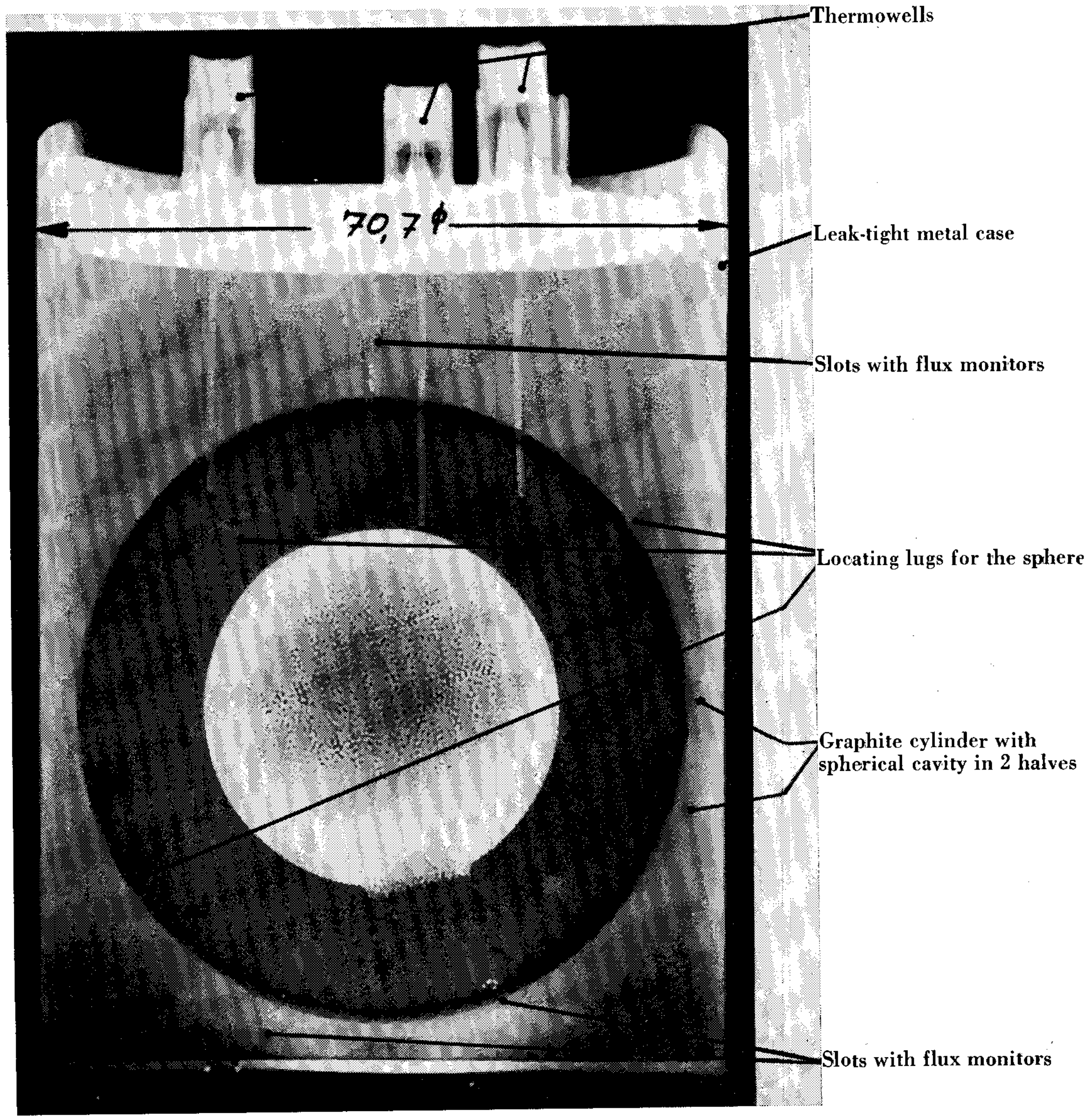


Figure 8

Radiograph of an instrumented capsule for the irradiation of fuel particles in a graphite sphere

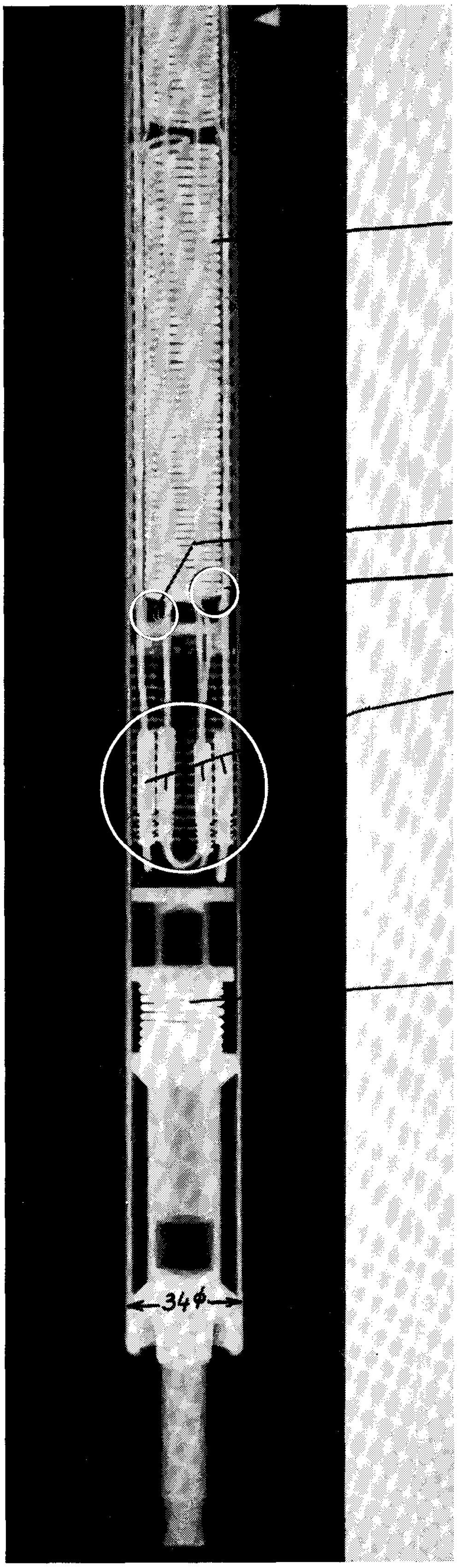


Figure 9

Radiograph of a leak-tight instrumented capsule for the irradiation of graphite

4. THE REACTOR AND ITS USE

In 1965, the core geometry was enlarged and the fluxes available increased. The reactor operated regularly for 190 days (222 in 1964), dissipating an energy of 8600 MWd (7600 in 1964). No serious incident occurred. The experimental load was increased from an average of 30 devices at the beginning of the year to about 40 devices at the end.

4.1. Operation of the reactor

During the first half of the year, the reactor operated with the same core geometry as in 1964 (geometry No. 5A, 20 fuel elements, 34 MW). During the second half of the year, a new geometry (No. 6) was introduced and gradually improved, the number of fuel elements being stepped up from 26 (6A) to 28 (6C), and the power being approximately 57 MW.

Configuration 5A, the characteristics of which were described in the previous annual report, had two drawbacks—it had only seven fast high-flux channels and had no large-section channel with a high thermal flux. It was for this reason that the new configuration was centred in the vessel, which made the central channel (H1) a very important thermal neutron flux facility.

Changing from one configuration to the other necessitated a period of tests, which, combined with a period of maintenance, lasted more than a month. During these tests, numerous physical measurements were carried out; in the case of configuration 6A, they showed that:

— for a total power of 57 MW, the maximum neutron flux at the start of the cycle was 425 W/cm^2 in the fuel plates;

— the maximum thermal-neutron flux in the central channel H 1 was 10^{15} $n/cm^2/sec$;

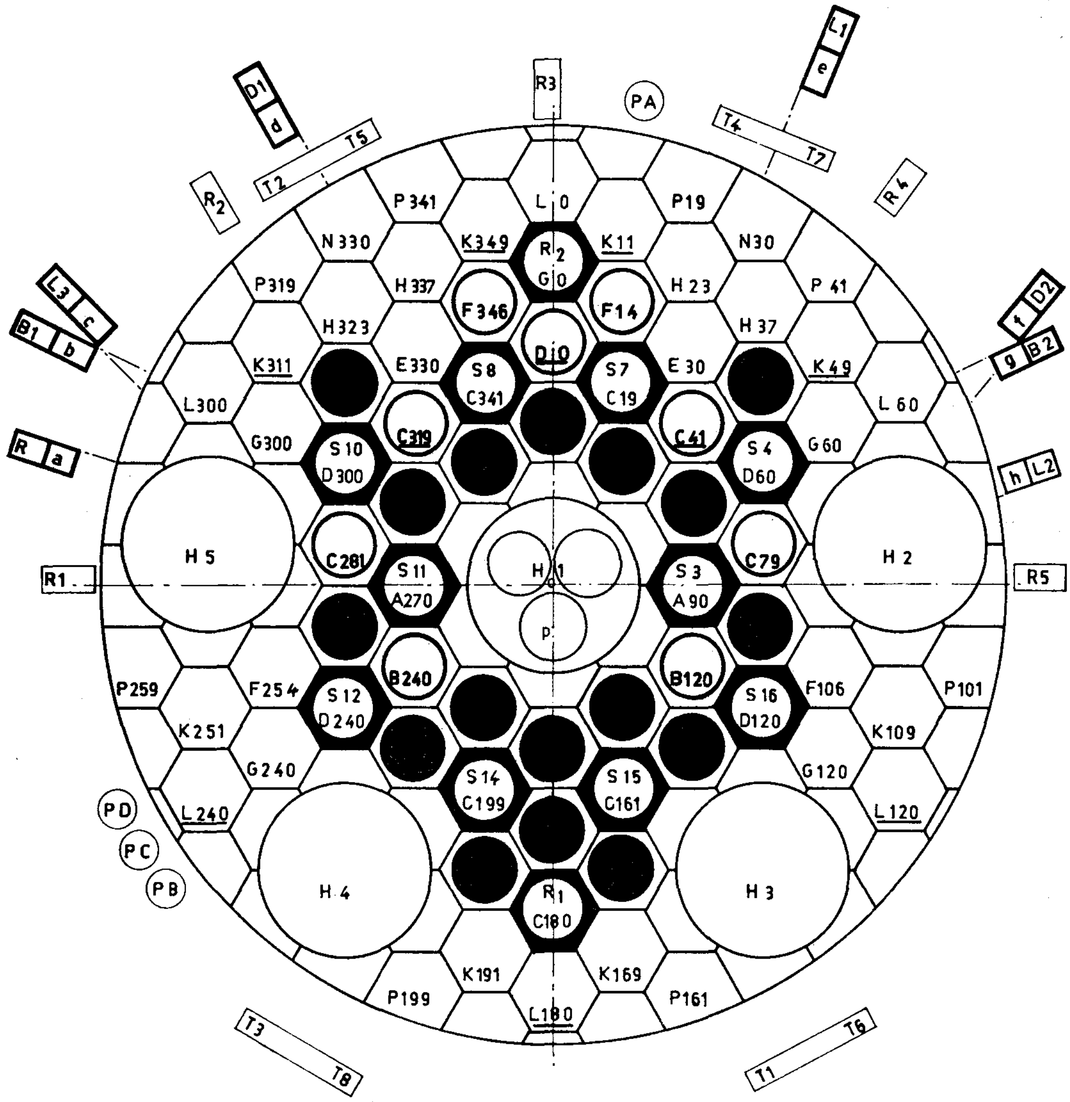
— the nuclear-heating calculation method was reliable and enabled a suitable choice of irradiation channel to be made.

In addition, simulations of incidents, with the primary-water flow shut off, showed that the new configuration was as reliable as the previous one provided automatic control of the by-pass valve of the reactor was used for accelerating the reversal of the primary flow. It was also found that flux control of the new core—which is much larger—called for the presence of at least two flux detectors (which could be experimental devices) to give the necessary response and eliminate the tendency of the fluxes to cause imbalance between each half of the core.

This period was also used for repairing the secondary cooling circuit. The ebonite lining of the flow-adjustment valve and the adjacent piping section became detached, upset the valve setting and blocked the distributors at the top of the cooling towers. A second adjustment of the valve throttle was necessary to make the whole unit operate correctly.

This testing and maintenance period was the principle factor accounting for the reduction in the number of operating days compared with the previous year (190 against 222 in 1964).

CORE CONFIGURATION (6A)



Control rod

Fuel element I
Burn-up : 15%

Fuel element II
Burn-up : 0%

Fuel element III
Burn-up : 30%

NUCLEAR DATA

CORE CONFIGURATION No. 6 A, AT A THERMAL POWER OF 57.6 MW

Channel	Fuel element mean burn-up %	Ø max (1) 10^{14} n/cm². s	Ø max / Ø average (2)	Nuclear heating (3) W/gr	Max Fast Flux > 100 keV (4) 10^{14} n/cm². s
Core positions					
A 30 — A 330	23.2	5.48	1.65	14.4	3.88
A 150 — A 210	14.4	*5.85*	1.51	16.1	4.85
BO	15.6	5.27	1.70	15.7	4.27
B 60 — B 300	14.4	4.47	1.70	13.1	3.72
B 180	15	5.42	1.56	16	4.45
B 120 — B 240	0	4.68	1.63	14.7	*5.02*
C 41 — C 319	0	4.00	1.71	14.1	4.28
C 79 — C 281	0	3.26	1.71	11.1	3.23
DO	0	3.84	1.72	14.6	4.11
F 14 — F 346	0	3.11	1.67	10.4	2.83
C 101 — C 259	26.3	3.74	1.63	8.8	1.98
C 139 — C 221	29.3	4.11	1.56	9.9	1.97
D 180	26.9	4.11	1.57	10.2	2.59
F 46 — F 314	29.1	2.79	1.65	6.4	1.06
F 166 — F 194	30.5	3.32	1.52	6.4	1.13
Typical reflector positions (Be filled)					
H 1 (O)	—	*10.2*	1.55	5.6	1.5
H 1 (P)	—	9.70	1.52	8.4	1.7
E 30 — E 330	—	*5.60*	1.69	5.5	1.1
K 109 — K 251	—	2.74	1.50	2	0.04
L 120 — L 240	—	1.74	1.52	1.5	0.01

The data are given for the beginning of a cycle, with a control rod position of 466 mm (rod tip at 14 mm below the reactor mid-plane)

(1) Unperturbed thermal neutron flux $(n)_o^{0,5}v_o$ et 2200 m/s, measured on the axis of a beryllium plug placed inside the fuel element or placed in the reflector channel. Multiply by 1.04 to obtain the Westcott flux $(n)_o^{\infty}v_o$ in the core.

(2) The average neutron flux is taken on the mean fuel length (762 mm).

(3) Maximum value measured in an aluminium plug placed inside the fuel element.

(4) Multiply by 0.622 to obtain the fast flux above 1 MeV. Values are measured on the axis of the beryllium plug.

The year was divided into cycles: seven cycles of three weeks each for the first half of the year, seven cycles of four weeks for the second half of the year. The relative operating period for these two systems did not differ much in theory, being 73.8 % and 73.2 % respectively.

The overall breakdown of the reactor dates was as follows.

	Duration in hours	*Relative Duration* in %
Operation	4560	52
Scheduled Shutdowns	3340	38.2
Unscheduled Shutdowns	860	9.8
	8760	100

The integrated power during the year was approximately 8600 MWd, which was in line with the consumption of about 10.7 kg U^{235}. The number of fuel elements used was 188, the average burn-up being 24 %.

The reactor operating parameters and operating characteristics are given in the following tables.

OPERATING CHARACTERISTICS OF THE REACTOR IN 1965

	1st half-year	*2nd half-year*
Nominal power	34 MW	57 MW
Total operating time	99 days	91 days
Operating time per average cycle	340 hours	310 hours
Energy dissipated per average cycle	490 MWd	740 MWd
Quantity of U^{235} at start of cycle	4.2 kg	5.7 kg
Core configuration	5A	6
Number of fuel elements	20	26 (6A) 28 (6C)

Hydraulic circuits (configuration 6C)

	Primary	*Secondary*	*Pools*
Flow-rate, m^3/h	5.600	4.400	400
Inlet temperature, °C	40	25	32
Outlet temperature, °C	46	15	34
Pressure, pump outlet, kg/cm^2	14.8	—	—
Pressure, reactor inlet, kg/cm^2	12.5	—	—
Δp on the core, kg/cm^2	2.8	—	—
pH	5.8 - 6.3	5.5 - 6.5	5.5 - 6.5
Resistivity, Ω/cm	$1\text{-}1.6 \times 10^6$	10^5	1.3×10^6
Purification flow-rate, m^3/h	20	100	20
Activity, μC/cc	10^{-1}	negligible	10^{-4}

Uranium plates

Nominal maximum temperature at hot spot	149-157 °C
Maximum heat flux	425 - 470 W/cm^2
Water velocity between plates	10 m/sec

Liquid effluents per average cycle

Cold, $< 10^{-5}$ μC/cc	1,100 m^3
Tepid, $10^{-5} - 10^{-2}$ μC/cc	755 m^3
Hot, $10^{-2} - 1$ μC/cc	215 m^3

Gaseous effluents

Air, containment-building outlet	38,000 m^3/h
Air, machine-hall outlet	150,000 m^3/h
Radioactivity	$< 10^{-10}$ μC/cc

Consumption

	in 1965	*per average cycle*
Electricity	16,210,000 kWh	1,160,000 kWh
Demineralized water	215,800 m^3	15,400 m^3
Uranium U^{235}	10.7 kg	765 g

4.2. Incidents during operation

The reactor was shut down for about 10 % of the time owing to incidents that occurred during operation. The causes of the unscheduled shut-downs break down as follows:

Incidents and unscheduled shut-downs	*Duration of shut-down* hours	*Relative duration* %
Release of control rods	80	9.2
Other failures of reactor installations (heat exchangers, pumps, electrical circuits)	270	31.3
Insufficient reactivity (owing to change of core)	248	28.8
Human errors	153	18.1
Failure of irradiation devices	109	12.6
Total	860	100

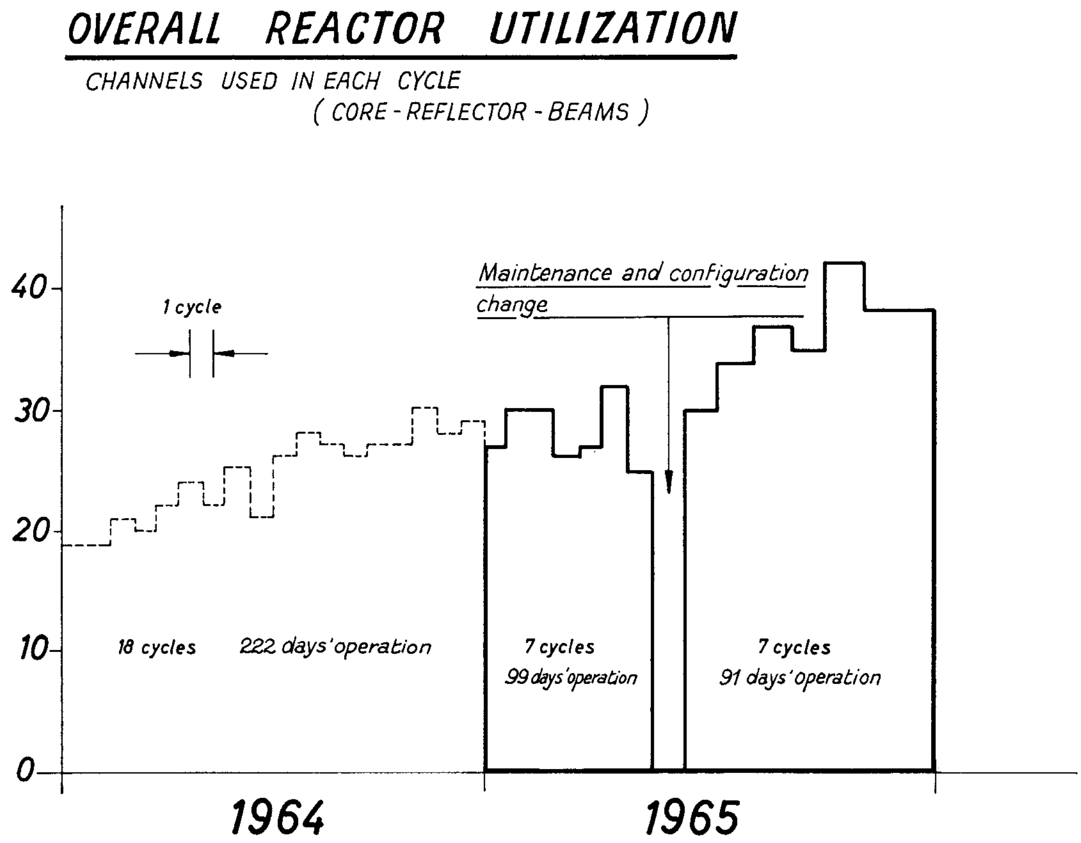
Unscheduled releases of the control rods, which in 1964 were by far the most frequent cause of stoppages, were rare in 1965. This was due to the improvement of maintenance techniques and the extensive use of preventive maintenance.

Other failures of the reactor installations were due to mechanical and electrical defects. Six tubes of a heat exchanger in the primary circuit were pierced in the course of the year. It was found that on each occasion the piercing occured at right angles to a central baffle as a result of chafing of the tubes in the holes of the baffle. A remedy is at present being sought for this fault in the design. The down time due to this cause amounted to 116 hours. Several electrical failures occurred in the control circuits and feed system, resulting in shut-downs which totalled 139 hours.

Shut-downs due to insufficient reactivity were another important cause of stoppages (28.8 %); these were attributable to the change-over to the new core configuration, which proved to be more sensitive to the absorbants than had at first been expected. After various remedies had been tried the solution eventually adopted was to remove two of the ten control rods and replace them by two fuel elements which were more than 15 % depleted. This made it possible to attain operating times of at least ten days per half cycle.

Finally, il should be noted that human errors and failures of experimental devices were more numerous than in 1964. The former were undoubtedly due to too frequent changes of reactor-operating personnel, while the latter were attributable to the installation and development work on a gas loop.

In March an unscheduled reactor shut down occurred in rather unusual circumstances. While checking the temperatures of the samples in a movable device, the experiment operator performed an incorrect action which set off the signal for automatic extraction of the experiment. At the same moment the reactor operator was engaged on a rod transfer, a frequently performed operation involving the putting out of action for a few seconds of the "group insertion" signal for the automatic release of a group of rods, which is one of the first safety measures to take effect in case of danger and which is actuated by the regulating rod when it reaches its lowest position. Contrary to expectations, the withdrawal of the experiment released an amount of reactivity greater than that taken up by the regulating rod, and since the "group insertion" was out of action the reactor power increased. At 110 % of the nominal power the "reverse" action (automatic slow insertion of all the rods), which should then have intervened, failed to function (a drive cam was maladjusted). The power continued to rise to 123 % of nominal and at that moment the "relay scram" action shut down the reactor. Although this power excursion had no further consequences it served to show that the simultaneous occurrence of several failures is always possible and that this is what really creates the danger.



4.3. Reactor equipment

Several important jobs were done, either in order to facilitate the use of the installations by the experimenters or else to improve the operational safety or the understanding of the reactor. Worthy of mention are: the installation of a third filter in the flushing circuit for the inlet filters of the primary purification system; the installation of a pump in the purification circuit; the construction of sound insulation for the pool pumps; the fitting of NaK detectors in the primary circuit; the extension of the electricity supply networks for the experimenters; the provision of measuring instruments for configuration change-over; the placing of cobalt in a control rod; the construction of a second hydraulic conveyor.

4.4. Reactor utilization

The loading of the reactor with experimental devices increased during the year under review, 35-40 channels being almost continuously occupied.

The distribution of the samples, in capsules x cycles, is as follows (a cycle represents 325 hours of irradiation):

A.	*Studies on radiation effects*	
	— Construction materials:	
	graphite	84.5
	steel	21.5
	beryllium oxide	9
	zirconium	1
	zirconium hydride	2
	niobium (ceramics)	1
	miscellaneous (crystals)	0.5
	beryllium	3.5
		123
	— Fuels	
	uranium oxide	14
	mixed oxides of uranium and plutonium	6
	mixed carbides of uranium and plutonium	1
	uranium/aluminium alloys	1
		22
B.	*Nuclear transmutations*	
	— Cobalt	132.5
	— Iridium	76
	— Transplutonium elements	13.5
	— Other radio-isotopes	58
		280
C.	*Neutron-beam experiments*	77
D.	*In-pile dosimetry*	35
	Total	537

The breakdown of the principal targets by client was as follows:

French Atomic Energy Commission (CEA)	Graphite, steel, beryllium-calcium, lithium, bismuth, cobalt, mixed carbides of uranium and plutonium
United Kingdom Atomic Energy Authority (UKAEA)	Graphite, steel, beryllium oxide, beryllium, glass (γ)
Dragon Project (OECD)	Graphite
T.H.T.R. Project (K.F.A. Jülich/EUR)	Graphite, beryllium, uranium oxide
German firms and research centres	Steel, zirconium hydride
Belgian firms	Steel, radium, mixed oxides of uranium and plutonium (EUR, CEN, BN)
SERAI (Brussels)	Uranium oxide, steel (Japan)
CEN (Mol)	Boron steel, uranium oxide, neutron beams, cobalt, iridium, antimony, other isotopes
EURATOM	Niobium, americium, uranium/aluminium alloys

The most noteworthy irradiation was that of the sodium loop (MFBS), which was performed in cycle 11 and necessitated a complete change of fuel elements owing to its high antireactivity.

For description of the conditions under which the principal irradiations were carried out, the reader is referred to Chapter 2.

5. PHYSICS STUDIES

At the disposal of physicists is the BRO 2 reactor, which is a zero-power model of the BR 2, and a well-equipped dosimetry laboratory. The studies carried out in BRO 2 during 1965 resulted in a better understanding of the new core configuration and enabled the irradiation conditions for new experimental devices to be determined. The routine dosimetry of irradiations performed by clients was continued. A consolidated report on the knowledge acquired of the BRO 2 reactor physics was presented at the E.A.E.S. conference held at Grenoble in November.

5.1. The BRO 2 reactor

The reactor was used primarily for the purpose of gaining a better understanding of the new BR 2 core configuration (No. 6), which was necessitated by the extension of the irradiation programmes. In its initial form (26 fuel elements, 10 control rods) this configuration proved to be insufficiently reactive and it was necessary, proceding in stages, to dispense with two control rods and replace them by two fuel elements. It was also found that the new configuration was very sensitive to local imbalances between the absorbent and the fissile masses, especially those due to the unequal consumption of the cadmium in the control rods. Numerous detailed measurements were carried out in connection with these problems. Furthermore, the presence of the MFBS loop, which is highly antireactive, necessitated an abnormally large uranium charge during the cycle in which the irradiation was performed, and this likewise called for exploratory measurements in the BRO 2 reactor.

Apart from the configuration studies, the BRO 2 reactor was used for predetermining the irradiation conditions. As regards the MFBS loop, for example, it was established that the specific power at the hottest point of the irradiated needle was 1,900 watts per cubic centimetre at a reactor power of 57.5 MW. Similarly, in the case of the CO_2-cooled Babcock loop the irradiation conditions for graphite samples were determined and all the parameters affecting these conditions were ascertained.

An extensive programme of high-antireactivity measurements was carried out with the aid of the pulsed and modulated fast-neutron source, the control unit being in its final version. This advanced technique and the results obtained were the subject of a report which was presented at the I.A.E.A. conference held at Karlsruhe in May.

5.2. The dosimetry laboratory

The insertion and analysis of irradiation detectors was continued on a routine basis both as a customer service and as an aid to the reactor operators (thermal- and fast-flux determinations, integrated-flux determinations, calorimetric measurements). In the course of the year integrated-flux measurements were carried out on some 40 devices. The equipment and techniques were adapted to the problems encountered, particularly in the case of very protracted irradiations such as those of the CEA's zirconium alloys, in which the thermal and fast doses to be measured are in the region of $10^{22} n/cm^2$.

Dosimetry work of a more general nature was continued, mainly with the object of monitoring irradiation damage. The accuracy of the measurements was increased as a result of the following activities:

— the definitive calibration of a primary sample spectrum (U^{235} fission spectrum, very high purity) and the drawing up of various secondary samples specially adapted to the problems under study;

— the increasing use of gamma-spectrography techniques on isotope mixtures and the development of a variable-aperture collimator for the extension of these techniques to sources with a high specific activity;

— the establishment, for the reactor core, of a virtually unique relation between the fission flux—a quantity measured by nickel, iron, titanium or copper detectors—and the neutron spectrum in the 0.1 - 10 MeV energy range.

These various activities were the subject of three papers read at the E.A.E.S. conference held at Grenoble in November.

5.3. Theoretical studies

In parallel with the tests, several theoretical determinations were carried out. The operating parameters of numerous experimental devices were analysed, in particular the antireactivity of the MFBS loop and of the Cobra furnaces.

A further study was made of certain fundamental problems, among which was the safety of and the calculation methods for the various types of BR 2 cells.

6. POST-IRRADIATION WORK

The use of the shielded dismantling cells adjoining the reactor was further intensified during 1965. The construction and installation of the scientific equipment for the medium-activity laboratory were completed and the laboratory was taken into regular use.

6.1. The very-high-activity cells (60,000 curies, 3 MeV)

The dismantling cells adjoining the reactor were occupied for a total of 691 hours (as against 685 in 1964) and 165 experimental devices were handled in them (compared with 76 in 1964). The work carried out included the sectioning of irradiated devices and the recovery of the targets, the reassembly of irradiated devices together with the insertion of cold or hot samples, and the loading of non-irradiated devices with hot targets. The most noteworthy operation was the post-irradiation dismantling of the in-pile section of the MFBS loop, which contained 10 litres o sodium and a plutonium pin; the actual operation took only one day and was completed without incident.

Besides the use made of the cells, the studies on cell equipment were continued with the aim of speeding up the work or effecting technical improvements. The cells were virtually closed down for two months so that two remote-controlled travelling cranes (20 tons and 3 tons) could be installed. The lighting at the various working levels was improved by the installation of quartz lamps.

In the pond adjoining the reactor use was made of the fuel-element examination device in order to inspect an irradiated ESSOR element and measure the distance between plates with the aid of potentiometric sensors.

6.2. The medium-activity laboratory

6.2.1. *The concrete cell* (1,000 curies, 1 MeV)

This cell was originally designed for handling a 1,000-curie source of transplutonium elements emitting 2.8×10^9 neutrons second; it is alpha-tight.

After the cell had been used early in the year for the extraction of curium (200 mg) from an americium-241 target (2.5 g) irradiated in the United States, it was converted step by step into a multi-purpose cell, notably by the installation of a lead entry-exit device identical with that installed in all the lead medium-activity cells. After final acceptance, the cell will be taken into intensive use in 1966.

6.2.2. *The lead cells* (180 curies, 1 MeV)

Construction work on the 15 cm-thick lead cells, which began in May 1964, was completed in September 1965 and all the cells were taken into use.

The "workshop " cell serves for the preparation of samples for subsequent analysis.

The "hardness and heat-treatment" cells are used for Vickers and Rockwell hardness determinations. Heat treatment and thermal cycling can be carried out in two furnaces at temperatures of up to 1,100 °C under vacuum or in an inert atmosphere.

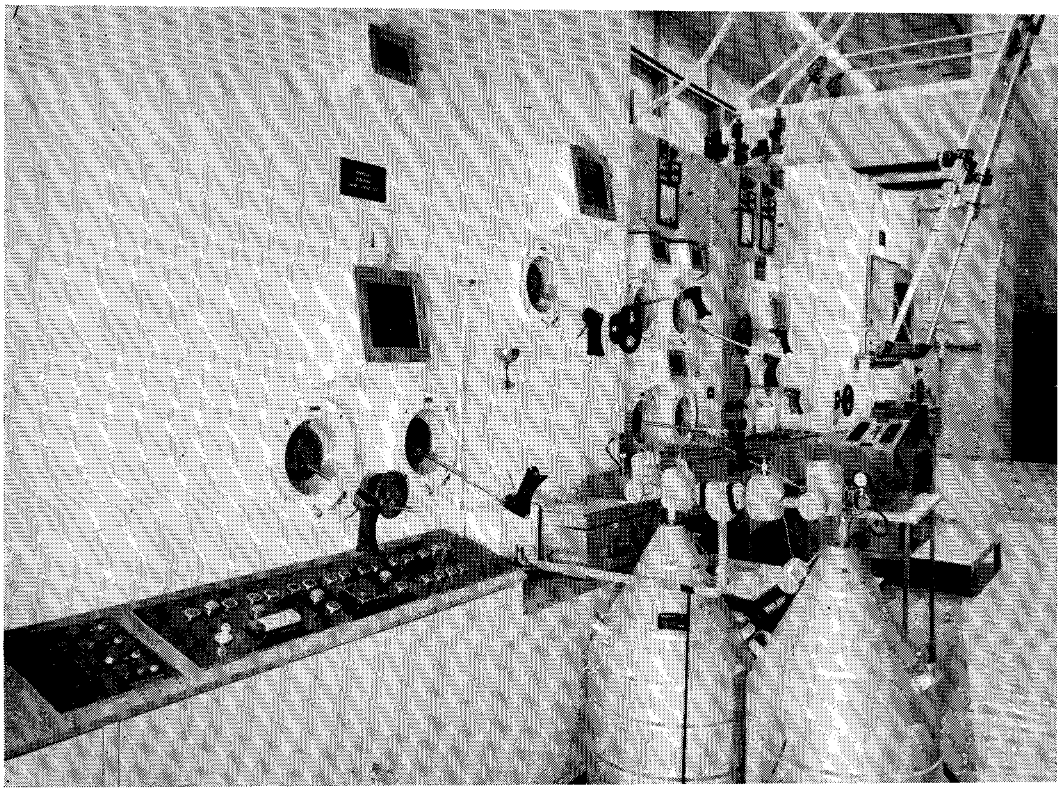


Figure 10

Front wall of the mechanical-tests cell installed in the Medium-Activity Laboratory

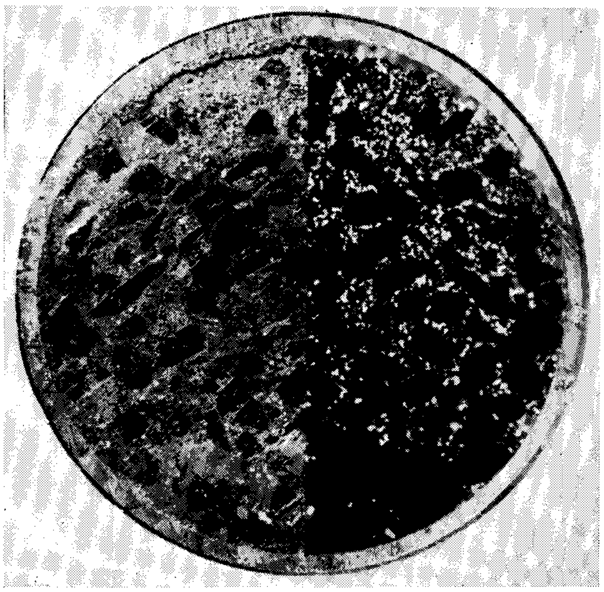


Figure 11

Metallograph/autoradiograph of a sample taken form a UO_2 - 4 % PuO_2 rod irradiated in the BR 2 reactor and examined in the Medium-Activity Laboratory. The left-hand half is a macrograph (× 5) of the the sample. The autoradiograph of the same zone is shown enlarged on the right-hand half of the photograph.

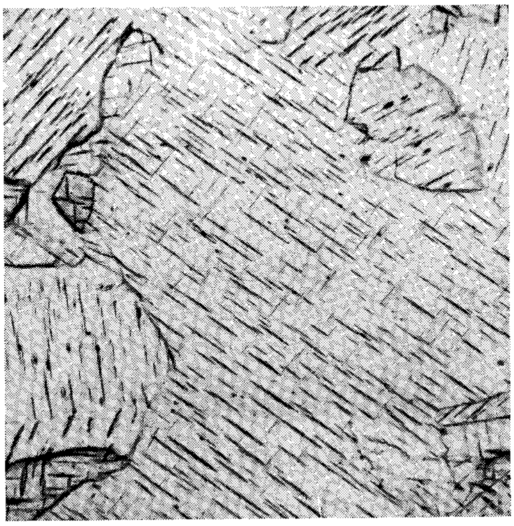


Figure 12

This micrograph (× 200) shows the ε phase of zirconium hydride irradiated in the BR 2 reactor. The post-irradiation examinations were performed in the Medium-Activity Laboratory.

The "physics measurements" cells contain various devices for measuring the dimensions, density and electrical resistivity of samples up to 200 mm long.

The "metallography" cells comprise five sample-preparation stations and one microphotography cell. The latter is equipped with a Reichert Telatom remote-controlled metallographic microscope. The cells will be filled with inert gas in 1966.

The "mechanical testing" cells are fully equipped for impact- and tensile-strength tests.

Figure 13

Microstructure (× 100) of a sample of natural-uranium metal irradiated in the BR 1 reactor. The post-irradiation examinations were performed in the Medium-Activity Laboratory.

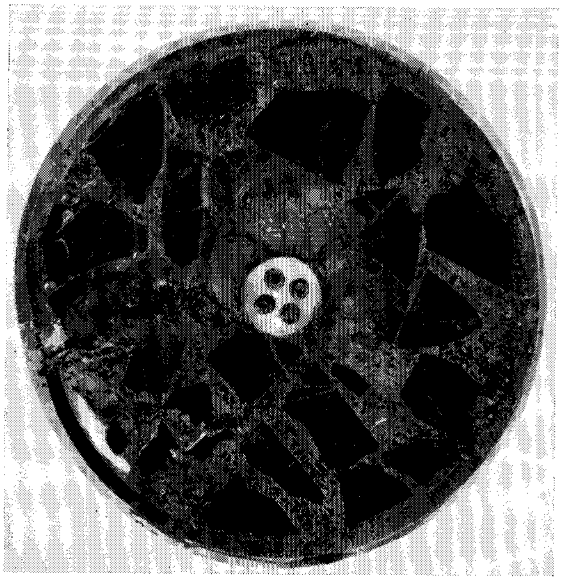


Figure 14
Macrograph (4: 1) of a vibration-compacted UO_2 sample extracted from a rod irradiated in the BR 2 reactor by means of the HR1 hydraulic conveyor. The post-irradiation examinations were performed in the Medium-Activity Laboratory.

The post-irradiation examination programmes carried out in 1965 related to targets of uranium oxide, UO_2/PuO_2 mixed oxides, uranium metal, ordinary steel, boron steel and zirconium hydride, all of which had been irradiated in BR 2.

6.2.3. *The analytical laboratories*

The laboratory for the physico-chemical analysis of irradiated graphite was used for the examination of samples from the Dragon project (O.E.C.D.). The time required for total-surface measurements was considerably reduced by the use of a "Betograph" automatic instrument.

The range of possible tests was extended by the procurement of a universal machine for mechanical micro-tests which is specifically intended for the future programmes with the Babcock-Wilcox (Oberhausen) loop, in which graphite will be irradiated under CO_2 at 400 °C.

The radiochemical laboratory was the scene of considerable activity. The development of methods for the determination of fission products by physical and chemical techniques was continued in collaboration with the CEN. A chemical decladding method for steel specimens was successfully used in the SERAI-Mitsubishi steel programme. The development of puncturing, gammagraphic and gamma-scanning techniques was also completed.

7. PERSONNEL AND FINANCIAL SITUATION

7.1. PERSONNEL

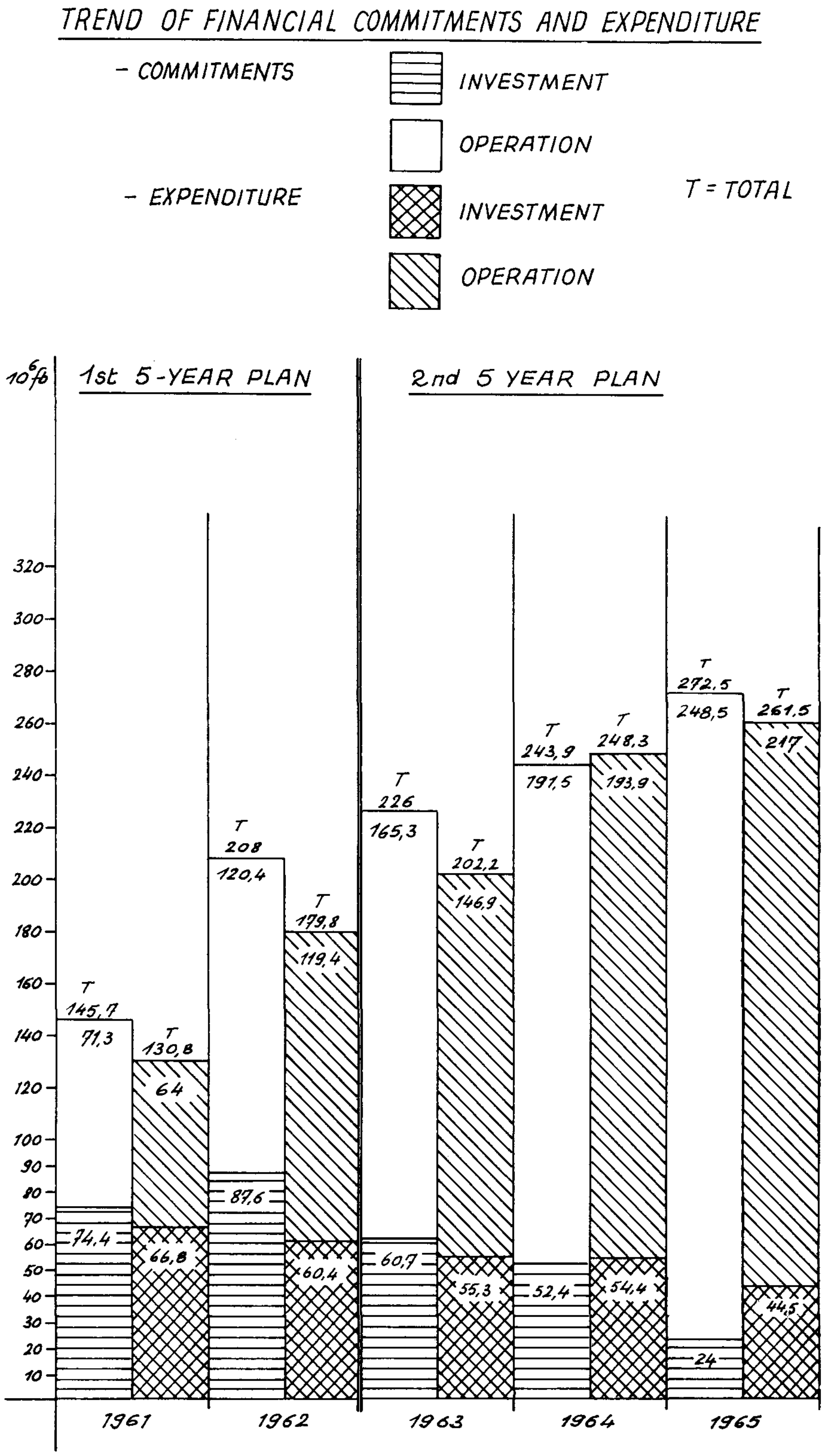
The operating staff is made up of both CEN and Euratom employees. The personnel strength at various times was as follows:

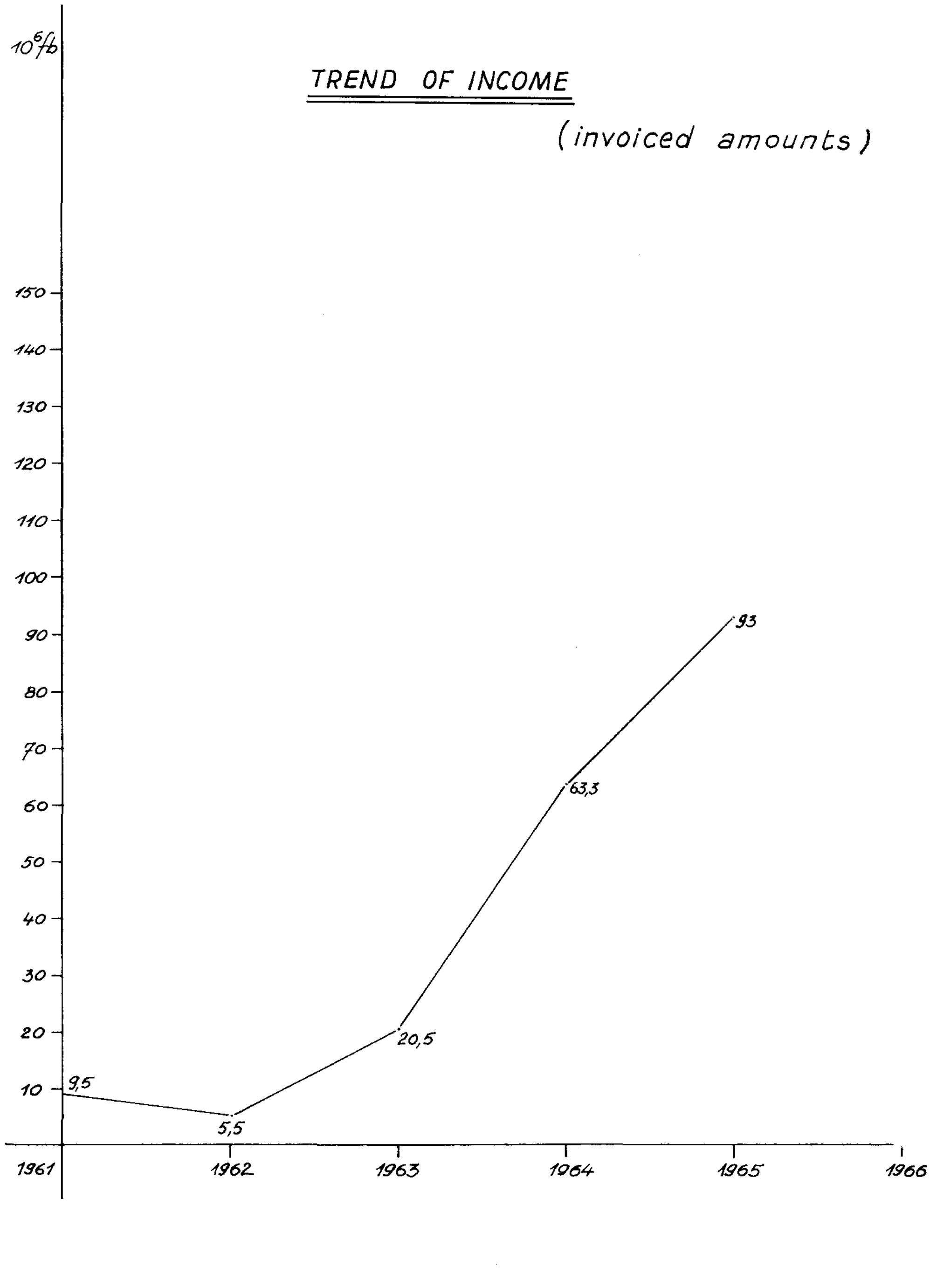
Year	*CEN employees*	*Euratom employees*	*Total*
as at 31-12-1961	133	33	166
as at 31-12-1962	156	36	192
as at 31-12-1963	191	40	231
as at 31-12-1964	214	41	255
as at 31-12-1965	215	42	257

It must be borne in mind that numerous functions are performed specifically by the CEN, e.g. dosimetry measurements, safety studies, radiation monitoring, workshop jobs and guard duties; for 1965 these services were assessed as the equivalent of 51 additional full time employees.

7.2. FINANCIAL SITUATION

The trend of financial commitments, expenditure and income is shown in the diagrams overleaf. Attention is drawn to the substantial reduction in investment, the trend of operating costs towards a steady value and, finally, the continuous rise of income.


TREND OF FINANCIAL COMMITMENTS AND EXPENDITURE
- COMMITMENTS
INVESTMENT
OPERATION
- EXPENDITURE
INVESTMENT
OPERATION
T = TOTAL
10⁶ fb
1st 5-YEAR PLAN
2nd 5 YEAR PLAN
320
300
280
260
240
220
200
180
160
140
120
100
90
80
70
60
50
40
30
20
10
T 145,7
71,3
74,4
T 130,8
64
66,8
T 208
120,4
87,6
T 179,8
119,4
60,4
T 226
165,3
60,7
T 202,1
146,9
55,3
T 243,9
191,5
52,4
T 248,3
193,9
54,4
T 272,5
248,5
24
T 261,5
217
44,5
1961
1962
1963
1964
1965



10^6fb
TREND OF INCOME
(invoiced amounts)
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
9,5
5,5
20,5
63,3
93
1961
1962
1963
1964
1965
1966

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To disseminate knowledge is to disseminate prosperity — I mean general prosperity and not individual riches — and with prosperity disappears the greater part of the evil which is our heritage from darker times.

Alfred Nobel

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